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A Literature Review Paper on Experimental Study on the Properties of Precast Concrete in Beam-Column Joints Using Polyvinyl Alcohol Fibres and Aramid Fibres with Half Grouted Sleeve Connectors

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A B S T R A C T

Using partially grouted sleeve connectors, this experimental investigation examines the performance properties of precast concrete beam-column joints reinforced with aramid and polyvinyl alcohol (PVA) fibres. The goal of integrating cutting-edge connector technologies and fibre reinforcing materials is to improve precast concrete assembly' earthquake resilience and structural integrity. The study consists of a set of lab tests intended to assess the overall behaviour, bond strength, and mechanical characteristics of beam-column joints under load circumstances that are simulated. In order to evaluate their impacts on joint performance, PVA fibre which are renowned for their high tensile strength and crack resistance—and aramid fibres, which are acknowledged for their superior durability and impact resistance—are included into the concrete mix. The usage of half-grunted sleeve connections lowers the risk of joint failure and increases the efficiency of load transfer. Comparing the joint to conventional precast concrete joints, the results show that the addition of PVA and aramid fibres greatly increases the joint's ductility, load-bearing capacity, and crack resistance. More improved load distribution and decreased slide at the interface are made possible by the half-grouted sleeve connectors, which result in stronger and more dependable connections. Regarding precast concrete systems, this study offers insightful information about the advantages of fibre reinforcement and creative connectors, which may lead to advancements in structural safety and building methods. Future design guidelines and the development of precast concrete technologies in seismically vulnerable areas are anticipated to benefit from the findings.

1. Introduction

Precast concrete has many benefits when used in structural systems, such as faster construction, better quality control, and increased longevity. Ensuring the performance of beam-column joints in precast concrete structures is still a significant challenge, especially when seismic loads are applied. Inadequate ductility, poor load transmission, and possible failure at the interfaces are among the common problems with traditional precast joints, which might jeopardize the structure's overall stability and safety. Using cutting-edge materials and creative connectors has become a more viable strategy to deal with these issues in recent years. Two such cutting-edge materials that may help to enhance the performance of precast concrete joints are aramid and polyvinyl alcohol (PVA) fibers. While aramid fibers offer high impact resistance and durability, PVA fibers are well known for their capacity to improve the tensile strength and crack resistance of concrete. When added to concrete, these fibers can greatly enhance the structural parts' mechanical qualities and serviceability. The connection mechanism that joins precast components is another essential component in enhancing joint performance. Half grouted sleeve connections are a creative way to improve the effectiveness of load transfer while lowering the risk of joint failure and slippage. The precast system's overall integrity and seismic resistance can be enhanced by these connectors, which offer a more dependable and effective connection between beam and column parts. In order to better understand the effects of PVA and aramid fibers on beam-column joint performance, this review paper will examine experimental studies and findings in this area. Additionally, the usefulness of half grouted sleeve connections in improving load distribution and joint behavior will be investigated. This work aims to provide a thorough knowledge of how these cutting-edge materials and connection technologies affect the performance of precast concrete structures by combining recent research and experimental data. The knowledge gathered from this assessment is meant to assist the creation of better design guidelines for precast concrete systems under seismic and high-load scenarios, direct future research, and direct practical applications.

2. Types of Precast Connections

There are two types of precast connections: wet and dry. Wet connections use grout sleeves or cast-in-place concrete for joint stability, whereas dry connections usually use mechanical fastening methods like bolting or welding. The enhanced structural stability of wet connections has led to their widespread adoption, particularly in seismic circumstances. This work focuses on wet connections, specifically those that join reinforcing bars in beam-column connections by means of grout sleeves

3. Research Background and Global Studies

Research from the United States, New Zealand, and Japan, among other nations, has contributed to our understanding of how precast concrete structures behave seismically. Notably, the development of seismic design guidelines was made possible by the Precast Seismic Structural System Research Program, or PRESSS. One important discovery was that precast systems were marginally less rigid at first than cast-in-place connections; however, some of these disadvantages may be overcome by innovations such as horizontal bar connections within joints.

1. Japan: Research conducted there found that, although some drawbacks such crack propagation were mentioned, the use of different types of grout sleeves improved the structural performance of precast connections.

2. New Zealand: Although such systems still required quality control during construction, research reported in New Zealand standards demonstrated significant gains in terms of seismic resilience, especially in joints where grout sleeves were used.

3. In the United States, the American Society of Civil Engineers (ASCE) and the American Concrete Institute (ACI) created rules for imitating cast-in-place detailing for precast structures, which laid the foundation for contemporary seismic design techniques.

4. Key Findings from Existing Literature

Various precast beam-column connection systems have been compared for performance in several experimental investigations. Among the important conclusions are a few of:

Daisuke (1993): compared three types of wet precast connections with cast-in-place connections and found that the initial stiffness and shear strength of precast connections were generally lower. The significance of the horizontal bar length in improving seismic performance was highlighted by the study.

In 1993, Uramoto conducted research on horizontal bar connections and came to the conclusion that longer bar projections resulted in better seismic behaviour.

According to Onur Ertas's (2006) experimentation, bolted connections yielded the highest strength and ductility among the five concrete frame connections tested. Wet connections with castings at the extremities of beams exhibited superior plastic hinge growth and dissipation of energy.

5. Challenges in Precast Connections

Maintaining uniform structural integrity throughout the connections is a recurring problem with precast concrete. Weak joints can cause premature failure under seismic loading conditions, which is where this problem is most noticeable. One of the key concerns is making sure that the cast-in-place areas and the grout sleeves continue to function as designed under seismic stress. Though they still lagged behind cast-in-place connections in certain areas, researchers like Vitaharya et al. (2012) discovered that precast connections might provide comparable seismic performance, particularly when utilizing innovations like stiffeners.

6. Experimental Advances in Grout Sleeves

The current study assessed how well precast beam-column connections with grout sleeves performed seismically. It was discovered that these sleeves had a major impact on the joints' stiffness, strength, and plastic hinge behaviour. While precast connections could achieve comparable seismic performance levels to cast-in-place specimens, variations in joint deformation and fracture distribution were noted. Grout sleeves were shown to be essential for preventing rebar slippage and guaranteeing that forces are properly transferred between linked pieces.

7. Practical Implications

1. Design Considerations: To guarantee that the joint can effectively transmit loads under seismic circumstances, the balance between mechanical interlock and grout bonding must be carefully considered during the design of half grouted sleeve connections. To reduce slippage and improve bond strength, this entails maximizing the sleeve's length, choosing high-performance grout materials, and making sure there is enough embedment depth.

2. Axial Compression Ratio: According to the experimental findings, joint performance is significantly influenced by the axial compression ratio. Axial compression increases joint stiffness but decreases displacement capacity, which is important for dissipating energy. Thus, it is imperative for designers to guarantee that the axial compression ratio is tailored to the seismic requirements of the building.

3. Quality Control in Grouting: The grout's quality has a major impact on how well the half-grouted sleeve works. In seismic conditions, any cavities, segregation, or irregularities in the grout mix can drastically weaken the bond and cause an early failure. Therefore, to guarantee long-term durability and performance, strict quality control must be implemented during construction.

8. Advantages:

1. Increased Stiffness and Strength: The incorporation of cast-in-place sections and grout sleeves greatly improves the stiffness and strength of the beam areas close to the joint, which helps to improve seismic performance. By guaranteeing a strong connection between precast parts, the grout sleeves were found to increase the strength of the connected components.

2. Energy Dissipation Capacity: The energy dissipation of precast specimens was adequate, which is important for earthquake performance. Precast specimens exhibited good energy dissipation and ductility, despite the cast-in-place specimen having a marginally higher load-bearing capacity.

3. Time and Cost Efficiency: When compared to conventional cast-in-place systems, the usage of precast components results in substantial savings in terms of construction time, labour expenses, and energy consumption. Because of its efficiency, it's a good choice for major construction projects.

4. Controlled Construction Quality: Pre-casting enables enhanced factory quality control, which can enhance on-site structural performance and material consistency. Additionally, by ensuring precise assembly of crucial connections, this strategy lowers variability.

8.1 Disadvantages

1. Reduced Seismic Integrity: The study shows that when the column-to-beam strength ratio is less than 1, precast connections with grout sleeves typically show shear failure. This suggests that precast connections may not be as structurally sound when subjected to strong seismic loads.

2. Cracking and Slippage in Joints: During testing, cracks both vertical and horizontal were seen in the grout sleeve regions. The overall stability of the structure is compromised by these fissures and rebar slippage, which show a lack of integration between the concrete and sleeves.

3. Difficult Assembly Procedure: Accurate joint and sleeve alignment is necessary during the on-site assembly of precast components, despite their rapid production process. Inadequate grout filling or misalignments might cause the structure to perform less well, particularly during seismic activity.

4. Pinching in Load-Displacement Behaviour: Precast specimens' load-displacement curves had more noticeable pinching than cast-in-place specimens', indicating higher degrees of bearing capacity degradation upon yielding. This restricts precast connectors' capacity to continue operating following an earthquake.

9. Experimental Findings and Implications

9.1. Earthquake Action

With a few exceptions, numerous experiments conducted under cyclic loads have shown that precast connections with grout sleeves behave seismically similarly to cast-in-place connections. Yan et al. (2018) discovered, for instance, that although precast connections exhibited energy dissipation that was similar to cast-in-place joints, they were more prone to cracking in the vicinity of the grout sleeves. This implies that the positioning of grout sleeves and the incorporation of concrete are essential for guaranteeing structural resilience.

9.2. Useful Applications

In real-world construction, these precast connectors are frequently used in seismically vulnerable mid- to high-rise structures. In China and Japan, these systems are frequently used in office buildings and residential towers; in areas with higher seismicity, additional precautions such prestressed grout sleeves are used. Precast members may more effectively transfer seismic stresses to one another thanks to the combination of horizontal and vertical rebar grout sleeves, which increases the structure's overall stability.

9.3. Design Guidelines and Suggestions

The results of practical and experimental applications have influenced the revision of design regulations in a number of nations. Grout-sleeve-based connections are covered in detail in both the ACI 550.1R-09 (USA) and the Code of Practice for Precast Concrete Construction 2016 (Hong Kong), which guarantees that these systems satisfy the seismic codes in their respective areas. To improve performance even more, though, more design factors like raising the column-to-beam strength ratio and raising the Caliber of the grout material are required.

10. Tensile Power

The compressive strength of the grout used in the sleeves and the precast concrete members both had a significant impact on the mechanical performance of the connections. The overall structural integrity of the connections was improved by the grout's substantially higher compressive strength than that of the concrete. The compressive strength of the grout after three days was continuously above 85 MPa, as observed in the test specimens; this was significantly higher than the 32 MPa of the precast concrete.

11. Rigidity

Joint shear distortion and load-displacement curves were used to assess stiffness. Because of the assembly interfaces in the precast connections, the precast specimens' initial joint stiffness was less than that of the cast-in-place specimen. Nonetheless, the grout sleeves' presence enhanced the beam's local stiffness close to the joint, offsetting some of the stiffness losses brought on by the interfaces. Additionally, it was noted that specimens with larger axial compression ratios showed more shear stiffness, which limited joint area deformation. The investigation showed that, in comparison to cast-in-place connections, the overall joint stiffness degraded more quickly in precast specimens during cyclic stress, even if the grout sleeves helped to increase localized stiffness.

12. Dissipation of Energy

One important metric for assessing the seismic performance of the beam-column couplings was energy dissipation. Due to bar slippage within the grout sleeves and weaker bonding at the assembly interfaces, precast specimens often dissipated less energy than their cast-in-place counterparts. The precast specimens' load-displacement hysteresis curves showed a more noticeable pinching effect as a result of this slippage (Fig. 25). The test results showed a direct correlation between energy dissipation and column-to-beam strength ratio, with lower energy dissipation observed in specimens with greater strength ratios. Higher axial compression ratios, on the other hand, were associated with greater energy dissipation, indicating that higher column compression enhanced joint behaviour.

13. Flexibility and Stiffness

The load-displacement behavior and the strain in the beams' longitudinal reinforcement were the main methods used to evaluate the deformation characteristics. Because of the grout sleeves' localized strengthening effect, the yield displacement of the precast specimens was often larger than that of the cast-in-place specimen.

14. Design and Configuration

The half-grouted sleeve connector is primarily used to join vertical rebars in columns. In this configuration, the sleeve connects one rebar via a mechanical screw thread on one end, and the other rebar is connected by grouting on the opposite side. The shorter length of the half sleeve compared to a full sleeve reduces material costs and allows flexibility in applications where space constraints are critical. The grouted connection, which relies on a mix of mechanical interlock and grout bonding, plays a crucial role in maintaining the structural integrity of the beam-column connection.

15. Earthquake Performance

15.1. Joint rigidity and shear capacity:

The maintenance of load transfer between the beam and the column depends critically on the seismic performance of half-grunted sleeves, particularly in beam-column joints. The study shows that the grout-filled sleeves can greatly increase the shear capacity of the junction when the column-to-beam strength ratio is maintained suitably. This is explained by the mechanical characteristics of the grout and the confinement it offers the rebar, strengthening the connection and delaying premature collapse.

15.2. Crack Distribution and Failure Modes:

Tests conducted under cyclic loading showed that because of stress concentration at the sleeve interface, cracks typically occur close to the grouted region. Because of the inadequate integration of the grout with the surrounding concrete, horizontal fissures appeared in the half-grouted areas of the columns. If not appropriately taken into consideration in the design, this fracture formation in seismic situations can cause a rapid loss of joint function.

15.3. Energy Dissipation:

The ability to dissipate energy is one benefit of using partially grouted sleeves. This is especially crucial in seismic zones where buildings experience frequent load cycles. According to the experimental findings, specimens with partially grouted sleeves display energy dissipation traits that are comparable to cast-in-place joints, however a performance decline was observed when the column-to-beam strength ratio was less than 1.

15.4. Rebar Slippage:

One important finding with the partially grouted sleeve system is that rebars can slip in the joint area, especially at high axial compression ratios. The efficacy of the joint is weakened by this slippage, which causes early failure. Half-grouted sleeves are more vulnerable to this problem than full-grouted systems, where the rebar is completely encased in grout, particularly if the grout quality or installation is not up to par.

16.Practical Implications:

16.1. Design Considerations:

To guarantee that the joint can effectively transmit loads under seismic circumstances, the balance between mechanical interlock and grout bonding must be carefully considered during the design of half grouted sleeve connections. To reduce slippage and improve bond strength, this entails maximizing the sleeve's length, choosing high-performance grout materials, and making sure there is enough embedment depth.

16.2. Axial Compression Ratio:

According to the experimental findings, joint performance is significantly influenced by the axial compression ratio. Axial compression increases joint stiffness but decreases displacement capacity, which is important for dissipating energy. Thus, it is imperative for designers to guarantee that the axial compression ratio is tailored to the seismic requirements of the building.

16.3. Quality Control in Grouting:

The grout's quality has a major impact on how well the half-grouted sleeve works. In seismic conditions, any cavities, segregation, or irregularities in the grout mix can drastically weaken the bond and cause an early failure. Therefore, to guarantee long-term durability and performance, strict quality control must be implemented during construction.

17. Conclusion:

Grout sleeves for precast beam-column connections exhibit promising seismic performance, particularly when paired with cast-in-place areas close to the joint to improve integrity. Even though these solutions function similarly to cast-in-place connections, more study is required to guarantee dependable joint behavior under high-intensity seismic loads and standardize building methods. In addition to providing insightful information on stiffness deterioration, energy dissipation, and fracture patterns, the study highlights the significance of grout sleeve design and the column-to-beam strength ratio in preserving joint integrity during earthquakes.

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